The SPIN Project: Testing of Safety and Performance Indicators

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Abstract: Safety and performance indicators, as meant in this paper, are quantities following from a numerical performance assessment calculation for a repository, which allow an evaluation of the results, either by providing a measure for the overall safety of the system (safety indicators) or by demonstrating the functioning of the barrier system (performance indicators). The most commonly used safety indicator is the effective dose rate, the use of additional indicators, however, may increase the trust in model calculations.

In the EC funded SPIN project a number of safety and performance indicators have been identified and systematically tested by re-calculating recent PA studies. The different indicators have been compared and assessed regarding their suitability and applicability in performance assessments. The indicator identification and assessment procedures are explained in this paper, and some results are presented.

1. INTRODUCTION

Safety and performance indicators have been under discussion for many years in several countries and international organisations. If those indicators refer to the long term safety of the total disposal system, they are often called safety indicators. If they refer to the performance of subsystems or the total system from a more technical point of view, they are sometimes called performance indicators. The need for indicators other than dose rate derives, e.g., from the long time frames involved in safety assessments of waste disposal systems and the increasing uncertainty in dose rate calculations over time due to uncertainty in evolution of the surface environment and of behaviour of man.

Before introducing additional indicators into a safety case of a potential repository site, the applicability and usefulness of different indicators have to be investigated and evaluated. The systematic analysis and testing of safety and performance indicators for use in different time horizons after closure of the disposal facility was the task of the SPIN project. This has been done by re-calculating four recent studies concerning repository projects in granite formations.

SPIN (Testing of **S**afety and **P**erformance **In**dicators) was the name of a research project, funded by the European Commission within the fifth EURATOM framework programme 'Nuclear Energy'. It has been carried out by eight organisations from seven European countries. These are GRS (Germany), Enresa (Spain), Nagra (Switzerland), Colenco, (Switzerland), NRG (The Netherlands), NRI (Czech Republic), SCK·CEN (Belgium) and VTT (Finland).

The work was co-ordinated by GRS. The project running time was September 2000 to October 2002. The final report will be available soon [1].

2. DEFINITIONS

It has to be clearly defined what is meant when talking about 'safety indicators' and 'performance indicators'. Since definitions of these terms have already been given by others, e.g. IAEA [2], it is not intended to give concurring definitions here, but some clarifications with respect to the special purpose of SPIN. In this context, safety and performance indicators are magnitudes following from numerical performance assessment calculations.

A safety indicator of the considered type must

- provide a statement on the safety of the whole system,
- provide an integrated measure describing the effects of the whole nuclide spectrum,
- be a calculable, time-dependent parameter,
- allow comparison with safety-related reference values.

A performance indicator of the considered type must

- provide a statement on the performance of the whole system, a subsystem or a single barrier,
- provide a nuclide-specific or integral measure,
- be a calculable, time-dependent or absolute parameter,
- allow comparison between different options or with technical criteria.

3. IDENTIFICATION OF SAFETY INDICATORS

The identification of safety indicators was mainly based on a study of open literature, supplemented by sysematic considerations. The effective dose rate was selected as the 'baseline' indicator, the other selected indicators are concentrations, fluxes or cumulated fluxes, using different nuclide weighting schemes. The following seven safety indicators have been considered:

- Effective dose rate [Sv/y]
- Radiotoxicity concentration in biosphere water [Sv/m³]
- Radiotoxicity flux from geosphere [Sv/y]
- Time-integrated radiotoxicity flux from geosphere [Sv]
- Radiotoxicity outside geosphere [Sv]
- Relative activity concentration in biosphere water [-]
- Relative activity flux from geosphere [-]

4. IDENTIFICATION OF PERFORMANCE INDICATORS

For identification of performance indicators different approaches have been used. In a first step the open literature has been studied and examined for proposals of indicators. These were supplemented by own proposals where it seemed sensible. To achieve a more systematic scheme of indicators, three concurring approaches were used. The first is based on five different quantities describing the behaviour of radionuclides in the individual barriers:

- the total amount of hazardous material in the barrier,
- the flux of hazardous material from the barrier,
- the released amount of hazardous material from the barrier,
- the concentration of hazardous material in the barrier,
- the transport time of the hazardous material through the barrier.

The changes of these quantities from barrier to barrier show the performance of the multi barrier system. The given quantities are therefore considered as performance indicators.

The other two approaches are based on so-called safety functions of the disposal system, which describe the basic functionalities of a deep underground repository. One was designed to identify a large number of indicators illustrating the functioning of the repository, allowing for some overlap between the indicators concerning the safety functions, and finally yielded the same indicators as found with the first approach. The other approach was aimed at

identifying a minimum number of indicators exactly representing the three safety functions 'isolation', 'delay and decay', and 'dispersion and dilution'.

Performance indicators refer to parts of the barrier system which are called compartments. Figure 1 shows graphically the different compartments and table 1 their use for different types of performance indicators.

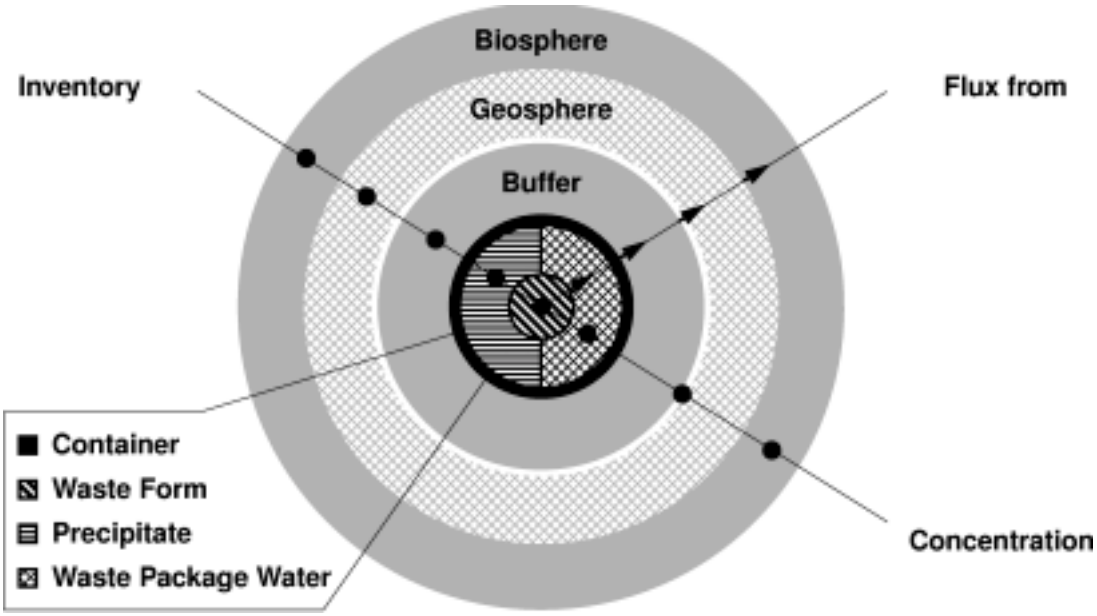

Figure 1: Graphical presentation of compartments and performance indicators

Table 1: Compartments used for different types of indicators

Compartments	Amount in	Flux from	Concentration in Water	Transport Time through
Waste form	x	x		
Precipitate	x			
Waste package		x	x	
Buffer	x			x
Near field		x		
Geosphere	x	x		x
Biosphere	x		x	

The following performance fourteen indicators have been considered:

- Activity in compartments
- Activity flux from compartments
- Time integrated activity flux from compartments
- Activity outside compartments
- Radiotoxicity in compartments
- Radiotoxicity flux from compartments
- Time integrated radiotoxicity flux from compartments
- Radiotoxicity outside compartments
- Activity concentration in compartment water
- Radiotoxicity concentration in compartment water
- Transport time through compartments
- Portion of not totally isolated waste
- Time integrated flux from geosphere / initial inventory
- Concentration in biosphere water / concentration in waste package water

5. CALCULATION

In the calculation phase, the identified indicators have been calculated for four different studies of repositories in granite. The studies differ in various details and parameters, like waste type, type of containers, nuclide inventory, source term, thickness of buffer, geosphere properties, and treatment of biosphere. The nuclide data, however, have been harmonised in order to get comparable results. To allow calculation of the indicators, the available assessment and post-processing tools have been modified where necessary, then the studies have been re-calculated. The four studies are: ENRESA-2000 (Spain), SPA-GRS (Germany), Kristallin-I (Switzerland) and TILA-99 (Finland).

For comparison, all results have been presented in a common style, and, where necessary, in common figures for different studies. The results have been compared with one another to assess their suitability for showing the safety of the system, or specific aspects concerning the performance of barriers. Some results are presented in figures 2 and 3.

6. REFERENCE VALUES FOR SAFETY INDICATORS

The calculated numerical value of a safety indicator can only provide a statement on the safety of the system if it is compared to a suitable reference value. The establishment of such values was an extra task within the SPIN project.

For the *effective dose rate* reference values are available from national regulations. These are in a range between $1 \cdot 10^{-4}$ and $3 \cdot 10^{-4}$ Sv/y.

For *radiotoxicity concentration in biosphere water* a reference values was determined from natural concentrations, using some outcome of the IAEA Co-ordinated Research Programme on Safety Indicators which was running in parallel, and other sources. Considering the nuclides K-40, Rb-87, Th-232, U-235 and U-238, some typical radiotoxicity concentrations in deep and shallow groundwaters of Finland, Switzerland and Czech Republic were selected and averaged to get a reference value of $2.0 \cdot 10^{-5}$ Sv/m³.

Fro radiotoxicity flux from geosphere, the determination of a reference value from natural sources requires a fixed catchment area. This was chosen to be 200 km² which seems fairly comparable with the area influenced by a deep repository. Again considering K-40, Rb-87, Th-232, U-235 and U-238 a reference value was derived from averaged natural fluxes reported by Miller [3] and found to be 60 Sv/y.

For *relative activity flux from geosphere,* constraint values are needed for each single nuclide instead of an overall reference value, which is then simply 1. For the purpose of SPIN those constraints were provided by the Finish regulation authority STUK.

For *relative activity concentration in biosphere water* also a complete set of constraint values is necessary. Such a set, however, could not established in a sensible way, therefore the indicator was not calculated.

7. ASSESSMENT OF SAFETY INDICATORS

To assess the applicabioty and usefulness of the indicators some criteria were defined. They were categorised in basic requirements and assessment crioteria. Basic requirements have to be met by every safety indicator, they were in principle applied during the selection process and checked again in the assessment procedure. The assessment criteria judge the usefulness of the indicators and thus facilitate a screening process. The requirements and criteria are compiled in the table below.

Table 2: Requirements and assessment criteria for safety indicators

Categories	Requirements and Criteria
Basic requirements	provide a measure of the safety of the total system
	safety-relevant reference values available
	safety-relevant weighting scheme available
	calculable by use of performance assessment models
Assessment criteria	easy to understand
	added value compared to other indicators
	biosphere pathways excluded
	dilution in aquifer water excluded

An overview of the assessment of safety indicators is given in table 3. Empty cells indicate that a unique answer cannot be given. It can be seen that even some basic requirements are finally not or not uniquely fulfilled by each of the selected indicators. The following conclusions can be drawn from the assessment:

- *Effective dose rate*: useful for all time frames, with higher preference for early time frames.
- *Radiotoxicity concentration in biosphere water*: useful for all time frames, with higher preference for early and medium time frames.
- *Radiotoxicity flux from geosphere*: useful for all time frames, with a higher for late time frames.
- *Radiotoxicity outside geosphere* / *Time-integrated radiotoxicity flux from geosphere*: not useful, because safety-related reference values cannot be established.
- *Relative activity concentration in biosphere water*: not applicable unless reference values are found.
- *Relative activity flux from geosphere*: not generally applicable unless reference values are found. The Finnish data are made for the Finish biosphere and are not sensible for general use.

Figure 2 shows the calculated results for the three indicators found to be useful, and a coparison between these indicators, normalised to their reference values.

Table 3: Overview of the results of the assessment of safety indicators

Indicator	Measure for system safety	Reference values available	Reference values safety-relevant	Weighting scheme available	Weighting scheme safety-relevant	Calculable by use of PA models	Easy to understand	Added value	Biosphere pathways excluded	Dilution in aquifer excluded
Effective dose rate	+	+	+	+	+	+	+	+	-	-
Radiotoxicity concentration in biosphere water	+	+	+	+	+	+	+	+	+	-
Radiotoxicity flux from geosphere	+	+	+	+	+	+	+	+	+	+
ime-integrated radiotoxicity flux from geosphere	+	+	-	+	+	+	-		+	+
Radiotoxicity outside geosphere	+	+	-	+	+	+	-		+	+
Relative activity concentration in biosphere water	+	-		-		+	+		+	-
Relative activity flux from geosphere	+	-		-		+	+		+	+

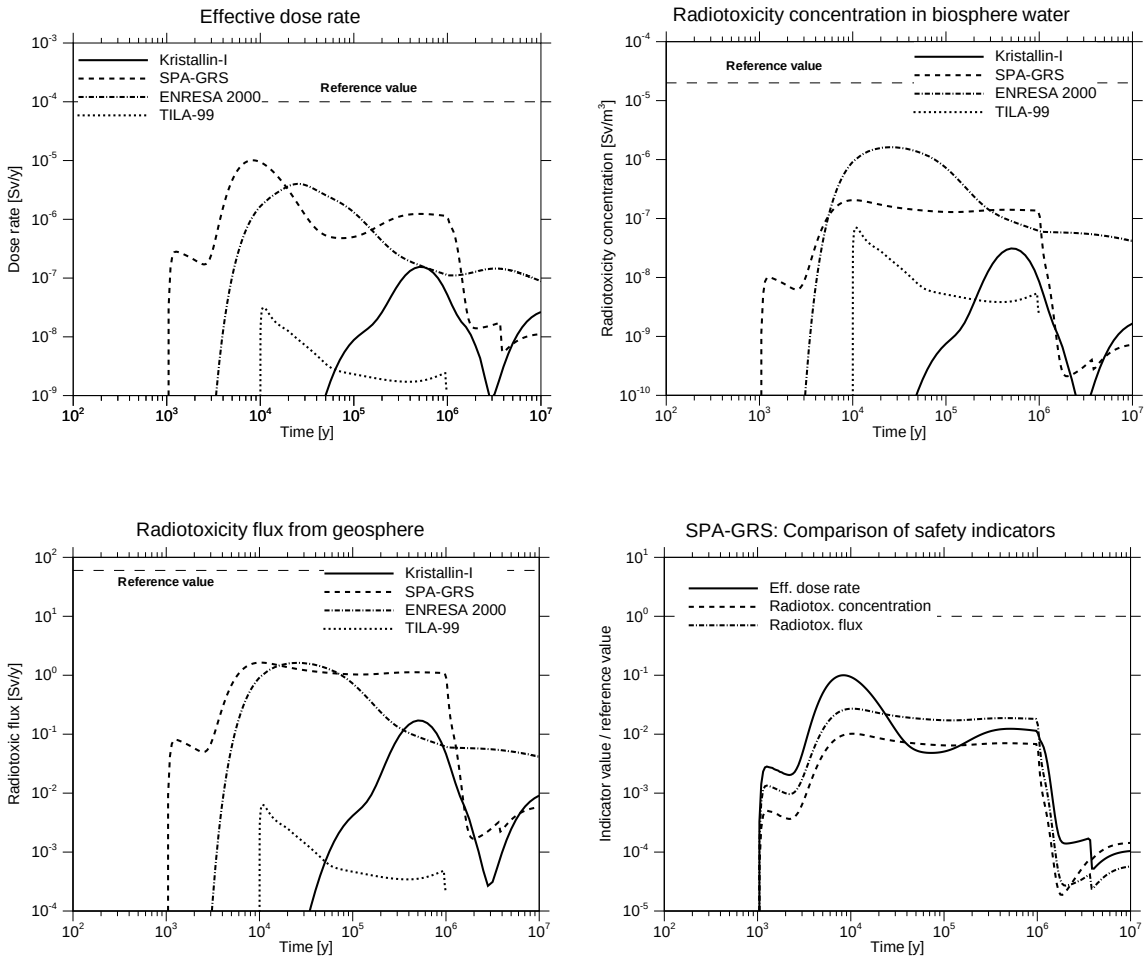

Figure 2: Safety indicator results

8. ASSESSMENT OF PERFORMANCE INDICATORS

The requirements and criteria defined for assessment of the performance indicators are compiled in table 4. They are less strict than those for safety indicators. A detailed assessment is not given here, it was found that each of the indicators is useful for a specific purpose. Some of them, however, provide more or less the same information, and the added value can be regarded to be low.

Table 4: Requirements and criteria for performance indicators

Categories	Requirements and Criteria
Basic requirements	measure for the performance of the system or subsystem
	comparison between options or with technical criteria
	weighting scheme available
	calculable by use of performance assessment models
Assessment criteria	easy to understand
	added value compared to other indicators

Results for the indcators *raditoxicity in compartments*, *radiotoxicity flux from compartments*, *time-integrated radiotoxicity flux from compartments* and *transport times through compartments* are presented in figure 3, each for one of the studies. While the first one shows where the radiotoxicity is at each instant, the second gives an impression of how it

moves through the barrier system. The third indicator shows the amount of radiotoxicity which finally reaches the biosphere. The differences between the values of the individual compartments show what part of the radiotoxicity has decayed during the transport through the barrier. The fourth indicator presented here is a graphical presentation of the nuclide-specific transport times through a barrier (here the buffer) versus their half-lives. It can give a rough impression of which nuclides will mainly decay during the transport and which will not.

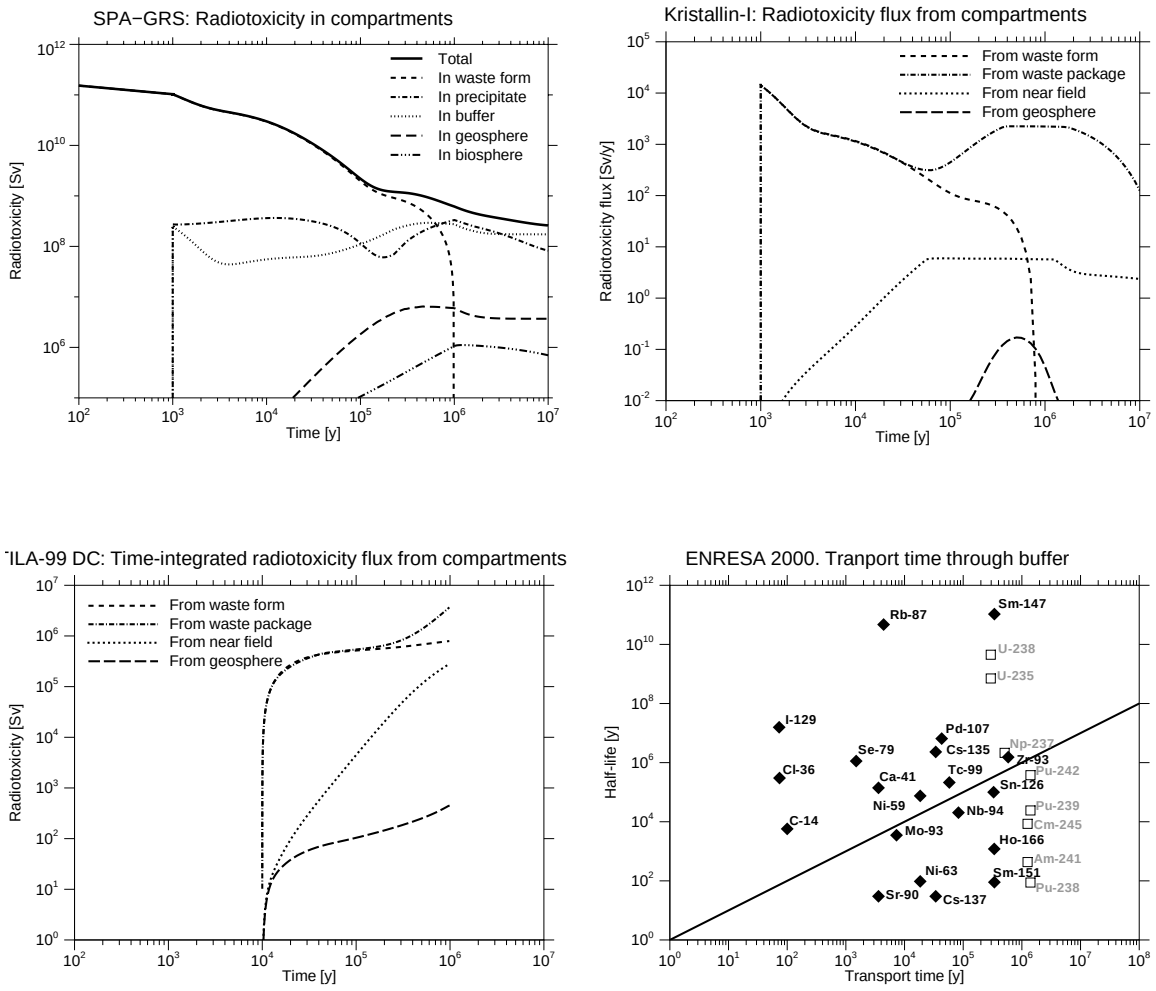

Figure 3: Performance indicator results

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[1] Becker, D.-A. et. al.: Testing of Safety and Performance Indicators. Final Report of SPIN project. EUR report, 2002 (in preparation).

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[3] Miller B. et.al., Natural elemental concentrations and fluxes: their use as indicators of repository safety, QSL-6180-2 version 2, March 2002.